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ORIGINAL ARTICLE - SPINE DEGENERATIVE

Preoperative radiographic clues for transdural disc herniation: could it be predictable?

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Abstract

Background Transdural disc herniation (TDH) is a rare event accounting for 0.3–1.5% of all disc herniation cases. Considering the risk of leakage of the cerebrospinal fluid from the dural defect after removal of TDH or incomplete removal, it is very important to recognize TDH before surgery. This study is a retrospective case analysis to analyze the imaging findings of seven cases and to construct a preoperative prediction model for TDH.

Methods Retrospective radiographic examination was performed among patients operated for TDH in two institutions from 2008 to 2018. The radiographic images were analyzed according to the following eight signs: including absence of dural tent, complete block of spinal canal, hawk-beak sign, double-layered lesion, increased distance between the dura and cauda equina, rim enhancement, dural tent enhancement, and epidural gas. To clarify the predictive ability of these radiographic signs, consecutive 131 surgically confirmed epidural disc herniation (EDH) patients for the last 2 years were set as a control group for TDH. The sum of radiographic findings was compared between TDH and EDH patients to determine the cutoff value.

Results There were 1 thoracic and 6 lumbar TDHs among 75 thoracic and 6674 lumbar disc herniation cases with an incidence of 1.33% and 0.09%, respectively. Dural tent ($p = 0.000$, odds ratio = 106.67), double-layered lesion ($p = 0.000$, odds ratio = 22.69), and distance between the dura and cauda equina ($p = 0.007$, odds ratio = 52.00) were statistically significantly different between TDH and EDH. According to the receiver operating characteristic curve, the cutoff value of 1.5 had 85.7% sensitivity and 90.8% specificity.

Conclusion Preoperative imaging can be useful for TDH diagnosis. It is safe to consider the possibility of TDH in patients with more than two findings in the preoperative images.

Keywords Transdural · Disc herniation · Preoperative · Magnetic resonance imaging

Introduction

The first technique of detecting transdural disc herniation (TDH) using magnetic resonance imaging (MRI) was developed by Epstein et al. [4] and Jenkins et al. [11]. In the natural course, the occurrence of TDH is a very rare event, which accounts for 0.3% and 1.5% of all disc herniation cases. The most commonly involved segment is the L4–L5 level, and 30–50% of the patients have a history of previous disc surgery [2, 13, 17].

Although there are a few literatures mentioning of imaging findings for predicting TDH, most of them are case reports describing the one of two findings in a fragmentary way. Kobayashi et al. analyzed four patients of TDH and described their clinical and radiographic characteristics; however, the efficacy has not been established due to the low incidence of the disease [13]. Preoperative recognition of TDH cannot be emphasized enough, as the extent of laminectomy and the need to perform durotomy depend on the suspicion. If TDH cannot be predicted in advance, surgeons may be confused because nerve retraction during surgery is more difficult than usual or they cannot find the proper lesion in correlation with

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the preoperative imaging findings. It may have a significant impact on the outcome of the TDH. Herein, we aimed to analyze the imaging findings of seven TDH cases experienced by the authors and to construct a preoperative prediction model for TDH.

Materials and methods

This retrospective study has been approved for research by the Institutional Review Board.

Study population

Medical records of two institutions from January 2008 to December 2018 were reviewed. Among the 75 thoracic disc herniation and 6674 lumbar disc herniation cases, who were surgically treated under the diagnosis of thoracic or lumbar disc herniation, one patient with thoracic TDH and 6 patients with lumbar TDH were included. Patients without preoperative MR images or computerized tomography (CT) were excluded.

Analysis of radiographic signs

Two neurosurgeons (M.S.K and K.H.K), who were blinded to all clinical and histopathological data, evaluated the MR images and CT scans on the presence of eight radiographic signs associated with TDH using a picture archiving and communication system. The 8 imaging findings were identified based on the signs reported in previous studies and the experience of the authors. They included (1) absence of dural tent, (2) complete block of the spinal canal, (3) hawk-beak sign, (4) double-layered disc herniation across the dura, (5) increased distance between the dura and cauda equina in non-enhanced MRI, (6) rim enhancement of disc herniation, (7) absence of enhancement of dural tent in enhanced MRI, and (8) epidural gas in the spinal canal in CT (Fig. 1).

The absence of the "dural tent" refers to an abrupt loss of continuity of the dura. Complete block of the spinal canal refers to the complete closure of the spinal canal with disc herniation in T2-weighted sagittal images. Hawk-beak sign is a sharp beak–like appearance of disc herniation on T2-weighted axial images. The double-layered disc herniation across the dura means that the disc herniation is observed in two layers based on the line estimated as the dura. The increased distance between the dura and cauda equina in non-enhanced MRI indicates that the distance is prominent between the dura and cauda equina in the axial cut immediately above the lesion. Rim enhancement of disc herniation is the enhancement that appears in the vicinity of the disc in the contrast-enhanced MRI. On contrast-enhanced MRI, the epidural venous space under the dural tent was contrast enhanced, and the distinction between CSF and low intensity was more prominent; thus, we analyzed the absence of the dural tent in contrast MRI separately. The presence of gas

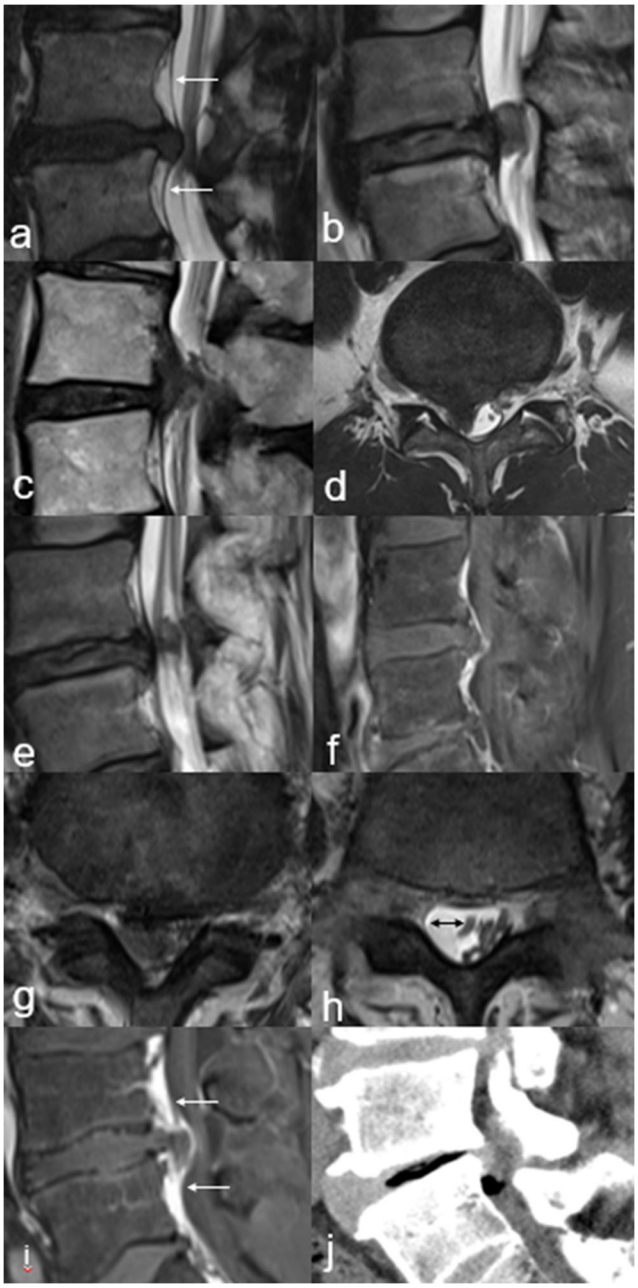

Fig. 1 **a** Dural tent. The disc herniation pushes the dura and forms a dural tent (white arrow). **b** Absence of dural tent. An abrupt loss of continuity of the dura is observed around the lesion. **c** Complete block of the spinal canal. The spinal canal was completely blocked with the herniated disc. **d** Hawk-beak sign. A beak-like herniation is seen in the right lateral recess in the axial plane. **e** Double-layered disc herniation across the dura. **f** Rim enhancement of disc herniation. **g**, **h** Increased distance between the dura and cauda equina in non-enhanced MRI. The distance between the dura and the cauda equina (left-right arrow) on the axial image (**h**) just above or below the lesion-level (**g**) is increased. **i** Enhancement of dural tent in enhanced MRI. **j** Epidural gas in the spinal canal in CT. MRI, magnetic resonance imaging; CT, computed tomography

within the spinal canal on the sagittal and axial planes of the CT was also examined.

Predictability of findings

To evaluate the usefulness of TDH prediction of the aforementioned imaging findings and to establish the cutoff value, we selected surgically confirmed epidural disc herniation (EDH) patients as the control group for TDH. To prevent heterogeneity in the control group, patient groups were recruited using the same 3.0-T MRI in a single institution. To reduce the selection bias, the period is limited to 2 years (from January 2017 to December 2018). A total of 131 patients were selected. We compared the numbers of the positive radiographic findings between 7 TDHs and the control group. When the two groups were compared based on a score system counting on image positive findings, the observed power was 1.000.

Statistical analysis

All statistical analyses were performed using SPSS (version 250 for Windows, SPSS, Chicago, IL, USA). Statistical differences in sex and the eight radiographic findings between TDH and EDH were analyzed using Fisher's exact test. One point was assigned to each of the radiographic findings that showed a statistically significant difference in the previous comparisons, and the scores were added. Based on the sum of the scores, we plot the receiver operating characteristic (ROC) curve for TDH predictability. A p value of < 0.05 was considered to indicate a significant difference

Results

A retrospective review of 11 years showed that one out of the 75 thoracic disc herniation cases had TDH. In 6674 lumbar disc herniation cases, six TDHs were observed. The incidence of thoracic and lumbar TDHs was 1.33% and 0.09%, respectively. Table 1 shows the basic demographics of the TDH patients. Patients' mean age was 44.2 years, and the L4/5 was the most common segments involved ($n = 3$). L5/S1 was not invaded in our patients. Four patients had previous lumbar surgery and one patient had a history of epidural neuroplasty.

TDH was predicted preoperatively in 5 patients, and wide subtotal or total laminectomy and intended dorsal durotomy were performed in 4 of these preoperatively diagnosed patients. In the remaining case, after partial hemilaminectomy, the herniated disc was removed without dorsal durotomy through the ventral dural defect at the shoulder of the root where the disc invaded. In the three patients who had a history of surgery for more than 10 years ago, additional facetectomy and interbody fusion or posterolateral fusion were also performed. TDH was not recognized before surgery in two patients. One patient with recurrent disc herniation 2 months after the first discectomy underwent revision discectomy. The patient had no improvement of symptoms and was found to have a remnant TDH in postoperative MRI. Finally, she underwent a third surgery including dorsal durotomy for removal of TDH and fusion the next day. The other patient had thoracic disc herniation, and the disc filled the canal, making it difficult to predict the transdural status. There were no cases of postoperative CSF leakage in all seven TDH cases.

Radiographic signs

Table 2 summarizes the presence or absence of radiographic signs observed in 7 TDHs. The most common positive findings were the absence of dural tent and double-layered lesion, which were both observed in 5 patients ($n = 5$, 71%). The contrast-enhanced MRI was performed in only 4 patients; of these, three had no enhancement of the dural tent ($n = 3$, 75%). Increased distance between the dura and cauda was seen in only 2 patients, including one patient with a past surgical history.

The frequency of 8 radiographic signs was compared between the seven TDH cases and 131 surgically confirmed EDH controls, and the results are described in Table 3. The absence of the dural tent was significantly more frequent in patients with TDH ($p = 0.000$, odds ratio = 106.67 (95% confidential interval [CI] 14.44–788.07)). Moreover, increased distance between the dura and cauda equina ($p = 0.007$, odds ratio = 52.00, 95% CI 4.01–673.51) and double-layered lesion ($p = 0.000$, odds ratio = 22.69, 95% CI 3.99–128.89) were also observed more frequently in the TDH patients. Other signs did not show statistically significant differences between the TDH patients and EDH controls.

ROC curve

ROC curves were estimated along with all the radiographic signs. The model showed excellent predictability with the area under the curve (AUC) of 0.945 (Fig. 2; $p = 0.000$). When the cutoff value of the radiographic signs was taken as 1.5, the sensitivity was 85.7% and the specificity was 90.8%.

Discussion

Recognizing TDH before surgery is important because the need for durotomy and tailoring of the laminectomy range for durotomy depend on this preoperative finding or suspicion. In addition, a microscopic or a wide-open approach may be safer than using endoscopy [13]. To confirm this, there have been various reports, but most of them were only case reports owing to the rarity of TDH cases, and one or two imaging findings were demonstrated [1, 6, 8, 10, 12, 13, 15,

Table 1 Demographics and clinical factors of patients with transdural disc herniation

Case	Age	Sex	Region	Segment	Previous history	Treatment	Intended durotomy
1	38	M	Thoracic	T10/11	No	Subtotal laminectomy	No
2	47	M	Lumbar	L3/4	Discectomy L3/4/5 bilateral 15 years ago	Total laminectomy	Yes
3	31	M	Lumbar	L4/5	Discectomy L4/5/S1 left 13 years ago	Posterior lumbar Interbody fusion	Yes
4	64	F	Lumbar	L3/4	No	Posterior lumbar Interbody fusion	Yes
5	38	M	Lumbar	L2/3	Two times of discectomy Level unspecified 10 and 20 years ago	Posterolateral lumbar fusion	Yes
6	35	F	Lumbar	L4/5	Epidural neuroplasty	Partial hemilaminectomy	No
7	60	F	Lumbar	L4/5	Discectomy L4/5 left 2 months ago	1st partial hemilaminectomy (failure) 2nd posterior lumbar Interbody fusion	No (1st) Yes (2nd)

17]. In this paper, we analyzed the previously reported findings and presented new imaging findings.

The absence of the dural tent is the same concept with that previously reported describing it as an abrupt loss of continuity of the posterior longitudinal ligament (PLL) [1]. Teng and Papatheodorou stated that the ventral dura and PLL are usually loosely connected [18]. If a disc herniation infiltrates only in an extradural space, it is expected that a room will be built between the posterior wall of the vertebral body and the dura by forming a tent shape around the lesion by pushing the dura in the dorsal direction. The absence of dural tent obviously indicates adhesion of the dura and PLL and the subsequent transdural violation. In the present study, there were 5 positive findings of the absence of the dural tent among the 7 TDHs, and the odds ratio of TDH in comparison with EDH was 106.67, which was the highest among the 8 imaging findings.

On the MRI with contrast, the extradural space could be identified more prominently than on the MRI without contrast, because the epidural venous plexus under the dural tent area was enhanced, irrespective of the ratio of the fat signal. Three of the four patients who underwent enhanced MRI showed a clear probability of transdural infiltration with this sign. However, there was no statistically significant difference between the TDH and EDH patients because of the small number of patients undergoing enhanced MRI.

Dandy suggested the pathophysiology of TDH, wherein the acute stress of the herniated disc may erode and then perforate the overlying dura [3]. Double-layered lesion is an extension of the concept of the absence of the dural tent, which means that disc herniation has two layers or different signal intensities at the border of the dura. Although the absence of the dural tent implies the adhesion between the dura and PLL, the double-layered lesion strongly suggests the possibility of transdural penetration. In our cases, this sign was significantly more frequent in TDH patients.

Increased distance between the dura and cauda equina is thought to be a pathognomonic sign of TDH. Hodge et al. found that irregular mass lesions located in the intradural region, as observed via myelography, are likely to have TDH [9]. Although this finding can also easily be confirmed on the MRI in the coronal plane, it is often difficult to apply because the spine MRI sequences in most hospitals do not contain a

Table 2 Radiographic signs in patients with transdural disc herniation

Case	Dural tent	Complete block of spinal canal	Hawk-beak sign	Double-layered lesion	Rim enhancement	Increased distance between the dura and cauda equina	Enhancement of dural tent	Epidural gas
1	Absent	Absent	Absent	Absent	Not performed	Not increased	Not performed	Present
2	Present	Absent	Absent	Present	Present	Not increased	Present	Absent
3	Present	Absent	Absent	Present	Not performed	Not increased	Not performed	Absent
4	Present	Present	Absent	Present	Not performed	Not increased	Not performed	Absent
5	Absent	Present	Present	Absent	Absent	Increased	Absent	Absent
6	Present	Present	Absent	Present	Absent	Increased	Present	Absent
7	Present	Absent	Absent	Present	Absent	Not increased	Present	Absent

Table 3 Comparison of radiographic signs between TDH and EDH

	TDH ($n = 7$)		EDH ($n = 131$)		p value	Odds ratio (95% CI)
	Positive	Negative	Positive	Negative		
Absence of dural tent	5 (71.4%)	2 (28.6%)	3 (2.3%)	128 (97.7%)	0.000*	106.67 (14.44–788.07)
Complete block of spinal canal	3 (42.9%)	4 (57.1%)	22 (16.8%)	109 (83.2%)	0.350	3.72 (0.78–17.78)
Hawk-beak sign	1 (14.3%)	6 (85.7%)	10 (7.6%)	121 (92.4%)	0.448	2.02 (0.22–18.44)
Double-layered lesion	5 (71.4%)	2 (28.6%)	13 (9.9%)	118 (90.1%)	0.000*	22.69 (3.99–128.89)
Rim enhancement	1 (25.0%)	3 (75.0%)	2 (16.7%)	10 (83.3%)	0.063	0.07 (0.04–1.02)
Increased distance between the dura and cauda equina	2 (28.6%)	5 (71.4%)	1 (0.8%)	130 (99.2%)	0.007*	52.00 (4.01–673.51)
Absence of enhanced dural tent	3 (75.0%)	1 (25.0%)	3 (25.0%)	9 (75.0%)	0.234	9.00 (0.66–122.79)
Epidural gas	1 (14.3%)	6 (85.7%)	3 (2.3%)	128 (97.7%)	0.190	7.11 (0.641–78.91)

TDH transdural disc herniation, *EDH* epidural disc herniation, *CI* confidence interval

*Statically significant

coronal image as a routine. The distance between the dura and cauda, which is measured just above or below the lesion level in the axial T2WI image, can be an alternative to the coronal plane for the examination of intradural infiltration. In the case of EDH, the subdural space collapses; thus, there is only a small distance or almost no distance at all. Given that the TDH spreads into the subdural space, the distance between the dura and cauda equina may be increased. However, this finding was observed only in 28% of the patients in our series. One patient without history of surgery and acute disc herniation who came to the hospital on the first day of symptom onset showed this sign. In the three cases with surgical history, only one had a positive finding. It is considered that an adhesion exists between the dura and cauda equina in the patients who had previously undergone surgery. Therefore, the interval did not increase despite the presence of chronic TDH.

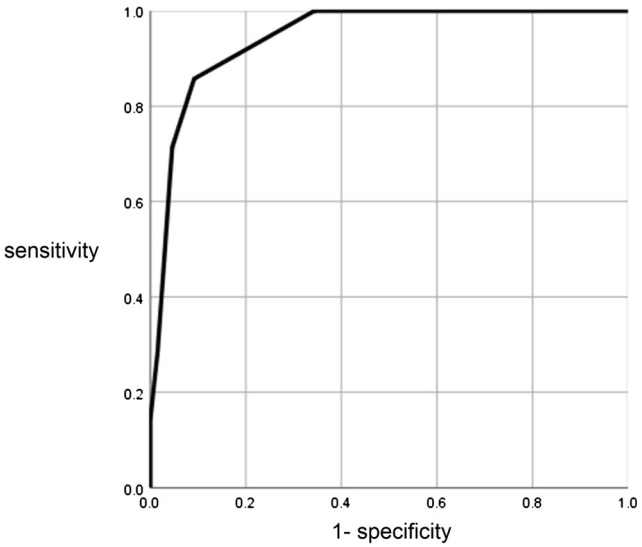

Fig. 2 A receiver operating characteristic curve of the eight radiographic findings. The area under the curve was 0.945. With the cutoff value of 1.5, the sensitivity was analyzed as 85.7% and the specificity was 90.8% ($p = 0.000$)

Some of the previously reported factors for identifying TDH were not significantly different between TDH and EDH. The finding of the complete block of the spinal canal was studied on the basis of myelography or myelographic CT, and it is reported to have a frequency of 65–90.5% in TDH patients [5, 12, 16]. However, this finding is not convincing because it is non-specific and implies only that the disc herniation is large. It is seldom possible to determine intra- or extradural origin of the lesion. Our results also did not show any significant difference when comparing TDH and EDH. The hawk-beak sign describes a disc herniation with a sharp beak–like appearance on an MRI T2-weighted axial image. The sharp angle is assumed to be reflective of disc fragments composed of sharp cartilaginous endplates [1, 7]. This finding is ambiguous in the criterion, and it is difficult to exclude subjectivity from the interpretation. In many EDH cases, the hawk-beak sign was observed and showed no statistically significant difference with that of TDH cases. The epidural gas sign was derived from a CT-based study, under the assumption that the frequency of epidural gas in the spinal canal was approximately 6 times higher in TDH patients than in EDH patients. Although the epidural gas was noted in only one case of TDH in this study, there was neither statistical significance nor causal relationship observed. Rim enhancement of disc fragment has been also mentioned to imply chronic inflammation or venous plexus and was referred to as a TDH-specific finding [6, 7]. However, this sign is also used when discriminating between disc herniation and tumor [14] and did not show a significant difference in comparison with the EDH cases.

Based on each imaging finding, a model for predicting TDH was constructed and evaluated. In order to prevent selection bias, surgically confirmed EDH was collected from a single institute for 2 years. Although the number of EDH groups is relatively high, the statistical power is 1.000 when the scoring system is compared, indicating that the probability

of type II error is very low. The model showed an excellent accuracy with an AUC of 0.945. When the cutoff value was 1.5, the sensitivity was 85.7% and the specificity was 90.8%. That is, if two or more imaging findings are present, the probability of predicting TDH is 86%, and if there are less than 1 imaging finding, the probability of predicting TDH is 9%.

The major limitation of this study is its retrospective design. Moreover, we only compared the TDH with a part of the EDH patients, who were surgically treated for last 2 years in a single institution. However, since there are only 7 TDH cases analyzed, it is possible that the statistical meaning may be diluted if compared with the total number of TDHs. Although these numbers are too small to derive clear conclusions, our findings are consistent with the results of previous studies and cannot be regarded as meaningless, considering the low incidence of the diseases. Studies involving a larger number of patients and using advanced imaging tools will elucidate the results of the present investigation.

Conclusion

In conclusion, preoperative imaging can be useful for TDH diagnosis. It is safe to consider the possibility of TDH if more than two suspicious findings are seen on the preoperative radiographic images.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (name of institute/committee) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

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